PATENT SPECIFICATION

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COMPLETE SPECIFICATION.

Improvements in or relating to Induction Motors with Phase Compensation.

We, DEUTSCHE WERKE, AKTIENGESELLSCHAFT, a corporation organised under German laws, of 90, Westfälische Strasse, Berlin-Wilmersdorf, Germany, Assignees of CARL ALTWICKLER, a German citizen, of 14, Rombergstrasse, Gotha, Germany, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

The invention concerns an induction motor with phase compensation, which carries in the secondary part, besides a winding connected to a commutator and serving essentially for excitation, a second phase winding, which is primarily designed to carry the proper working or load current, and the invention consists essentially in that the commutator brushes are set so that a working or load current also flows in the exciting winding, the strength of which current bears a definite proportion to that in the working winding whereby, according to the resistances of the exciting and working windings, the sum of the copper losses in the secondary part have a minimum value.

The arrangement of two separate windings in the secondary part of such a machine, which is usually the rotor, has inherent disadvantages. The space which exists for the lodgment of the winding is decreased by the division into two separate windings which must be insulated from one another, and consequently the copper mass for disposal is lessened. If a given current density is taken as a starting point, then the power which can be got out of the machine is fixed, and if a greater power is desired, then one must work with a higher current density. But the current density is limited owing to the heating effect which it has upon the windings, so that the power is limited by temperature considerations. Now by the present invention this restriction of the power due to heating is minimised by a definite apportionment of current between the two rotor windings which reduces to a minimum value the total losses in the windings by heat, as is set forth in the following discussion:

A compensated motor has to have in its secondary part the following currents:—

1. The current which helps to build the turning moment of the machine (working or load current).

2. The current which maintains the magnetic field (exciting current).

The latter must under all circumstances flow in the commutator winding. On the other hand the working current can be divided at will between the two windings.

In the following mathematical consideration:

i_f is the current necessary to generate the field (this is a wattless current),

i_m is the current necessary for the moment (this is a watt current),

$a.i_m$ is that portion of the working current which is allowed to flow in the exciting winding,

$(1-a).i_m$ the portion of the working current which continues to run in the working circuit,

r_k the resistance of the proper working winding, and

r_e the resistance of the commutator winding.

As i_m must be a watt current and i_f a wattless current, they have a relative time-phase difference of 90°.

Now if the whole working current i_m is allowed to flow in the working winding, the total copper losses in both windings together come to

$$V_1 = i_m^2 r_k + i_f^2 r_e.$$

[*Price* 1/-]

If on the other hand a part of this current i_m is transferred to the exciting winding, e.g. a portion ai_m and in the working winding a current of only $(l-a)i_m$ flows, then the total copper loss becomes.

$$V_2 = i_f^2 r_e + a^2 i_m^2 r_e + (l-a)^2 i_m^2 r_k$$
$$= i_f^2 r_e + i_m^2 [a^2 r_e + (l-a)^2 r_k].$$

The expression in the brackets becomes a minimum when

$$a\ r_e = (l-a) r_k.$$

that is, if $\frac{r_e}{r_k} = \frac{l-a}{a}$

or if $a = \frac{r_k}{r_e + r_k}$

In this case we have

$$V_2 \text{ (minimum)} = i_f^2 r_e + \frac{i_m^2 r_e r_k}{r_e + r_k}$$

The current which will then be passed over the commutator equals $\sqrt{i_f^2 + a^2 i_m^2}$.

Thus, in order to give the desired result, there must flow in the exciting winding a watt current which constitutes a specific proportion of the total working current, which proportion is dependent upon the resistances of the windings. It is therefore evident that if the resistances of the windings are given, the desired result can be obtained by proper adjustment of the conditions which determine the value of watt current which shall flow in the windings. This will depend upon the magnitude and phase of the voltage supplied to the commutator as well as upon the phase difference between this and that produced in the commutator winding, and since one of the factors determining these will be the position at which the brushes stand, the invention amounts to the obtaining of a motor with the brushes so set as to give the division of current as above specified.

It should be possible for the skilled designer of the kind of motor concerned to carry out the invention when designing such a motor, with the aid of the foregoing disclosure. The following description however will serve to indicate in what manner the invention may be readily applied to a motor which is already in existence.

Fig. 1 of the accompanying drawings shows schematically an example of compensated asynchronous motor to which the invention relates.

The stator of the motor carries first of all the primary winding 1, 2, 3 which is shown as a three-phase star-connected winding. A secondary or auxiliary winding 4, 5, 6 which is also shown as a three-phase star-connected winding lies together with and in inductive relation to the primary winding 1, 2, 3, upon the stator body and terminates in a three-phase arrangement of brushes 7, 8, 9, which are connected with the excitation winding 10 upon the rotor, so that the rotor is compensated, i.e. works with a power factor equal to unity. Upon the rotor is furthermore a three-phase working current winding 11, 12, 13 closed through slip rings, which determines the asynchronous running of the motor and has to convey essentially the working current which builds up the turning moment of the motor.

The adjustment of the brushes in accordance with the point of view given above, will naturally be done in manufacture, as if the brushes are once set so that the current is divided between the two rotor windings in the desired manner, there will be no need afterwards to alter this setting or division of current.

The desired adjustment can be effected on the lines of the considerations hereinafter set forth.

The resistances of the rotor working winding and the rotor commutator winding are first reduced to the same terms, for example with reference to the main stator winding; that is, as these windings in practice do not require to have the same effective number of turns, it is necessary, in order to be able to directly compare them with one another, to bring them to the same number of turns. For example, if one of these windings has turns w_1 and resistance r_1, then resistance of this winding with respect to one having turns

$$w_2 = r_1 \left(\frac{w_2}{w_1}\right)^2.$$

The equivalent resistance of the commutator winding which is calculated with reference to the number of turns of the main stator winding in the manner stated, is represented by r_e, and the corresponding resistance of the working winding by r_k.

Employing the formula $a = \frac{r_k}{r_k + r_e}$ deduced above, a part $a.i_m$ of the total necessary working or load current is calculated, which the commutator winding must take in order that the copper losses in the rotor are a minimum. In other words, if P is the normal useful output of the motor, then an amount a.P must be obtained from the commutator winding and an amount $(l-a)$P from the working winding.

Since the motor can give an output P

at the shaft with a slip σ, it must transfer an amount $\frac{P}{1-\sigma}$ from the stator to the rotor with the aid of the magnetic field. The difference of these two values, namely $\frac{P}{1-\sigma} - P = \frac{P.\sigma}{1-\sigma}$ is used as electrical work in the two rotor windings. If now the commutator winding is to give an output a.P, according to the foregoing, an electric power $a \cdot \frac{P.\sigma}{1-\sigma}$ (desired value) must be supplied to it. In the winding itself an amount $3i^2.r_e$ is wasted in heating the copper, (i being the total current in said winding). The difference between heating current loss and electro-magnetically produced energy (Pm) must be conducted to (or from) the winding electrically by way of the commutator. (It will be convenient to express all quantities in watts). Thus there is:—

Energy introduced electro-magnetically (desired value) $Pm = \frac{a.P.\sigma}{1-\sigma}$,

Energy used in heating current $= 3i^2r_e$,

Energy electrically introduced over commutator $= 3i^2r_e - Pm$.

This third amount is measurable, as also the currents, resistances and the slip, so that by measurement it can easily be determined what energy must be produced electro-magnetically in the winding, if the motor runs with full power at any given brush position. As the slip σ is mostly only very small (.02—.06) the power produced electro-magnetically is practically always less than that used in heating current so that nearly always electrical power is supplied over the commutator.

The desired adjustment of the brushes can be determined by measuring by means of a watt meter the electrical energy which is introduced to the commutator winding or flows therefrom under normal conditions of load. If the electrical energy flows to the commutator winding the motor runs below synchronism and the electrical energy introduced to the winding must be subtracted from that lost by heating current, in order to obtain that value of energy which must be produced electro-magnetically from the rotating field to the winding. If the measured and calculated value is less than that desired, it is evident that the commutator winding has too little effect upon the moment. In order to increase its torque producing capabilities, the brushes must be displaced oppositely to the direction of rotation of the machine, and the watt meter measurements repeated, till the point is found at which the desired value and the actual value of the energy produced electro-magnetically are equal. The brushes are naturally then fixed in the position found.

The following description with reference to the graphs shown in Fig. 2 of the accompanying drawings illustrating an actual case in practice will clearly indicate how the invention may be carried out:—

The machine tested was a 4-pole compensated three-phase asynchronous motor of 11 kilo-watts (50 cycles). The resistance of the rotor working winding referred to the main stator winding is .63 ohms. The resistance of the commutator winding similarly calculated is .97 ohms. Thus in the foregoing mathematical discussion $r_k = .63$, $r_e = .97$. This gives a factor a of .394, that is the commutator rotor winding must conduct 39.4% of the whole working current, so that it is divided in the same ratio in the building up of the torque and therewith also in the generation of the mechanical power.

The machine was fully loaded at different brush positions, and in each position the current in the commutator circuit and also the slip were measured. For convenience these are plotted, as shown in the upper graph. From these values the power ($\frac{a.P.\sigma}{1-\sigma}$) which must at each position be produced electro-magnetically in the commutator winding is calculated, and this value plotted as shown on the lower graph (curve I). From the power which is transferred electrically from the auxiliary stator winding to the commutator exciting winding, and which may be measured by means of a watt meter, as well as the current heat loss in the commutator winding, which can be readily calculated, the value of the energy which is actually produced in the commutator winding from the rotating field can be found. These values are also plotted upon the same graph (curve II).

It is seen that the two curves thus obtained across one another. The point of intersection X is clearly marked and this indicates the desired brush position.

We are aware that it has previously been proposed, in Specifications Nos. 10,611 of 1908 and 30,208 of 1909, to so arrange a motor of this kind that a torque producing current also flows in the exciting winding whereby under normal working conditions the rotor copper may be more fully utilised, thereby increasing the efficiency of the machine, but we are not aware that it has ever been suggested to apportion the working current between

the working current winding and the exciting winding in such a manner that the total copper loss in these two rotor windings becomes a minimum.

Having now particularly described and ascertained the nature of our said invention and in what manner the same is to be performed, we declare that what we claim is:—

Compensated induction motor for single or polyphase current having in the secondary part both an exciting winding fed over a commutator and a polyphase closed working winding, the commutator brushes being set so that a working or load current also flows in the exciting winding, the strength of which current bears a definite proportion to that in the working winding whereby, according to the resistances of the exciting and working windings, the sum of the copper losses therein is a minimum, substantially as set forth.

Dated this 8th day of October, 1924.

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Patent Agents for the Applicants.

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SHEET 1

[This Drawing is a reproduction of the Original on a reduced scale]

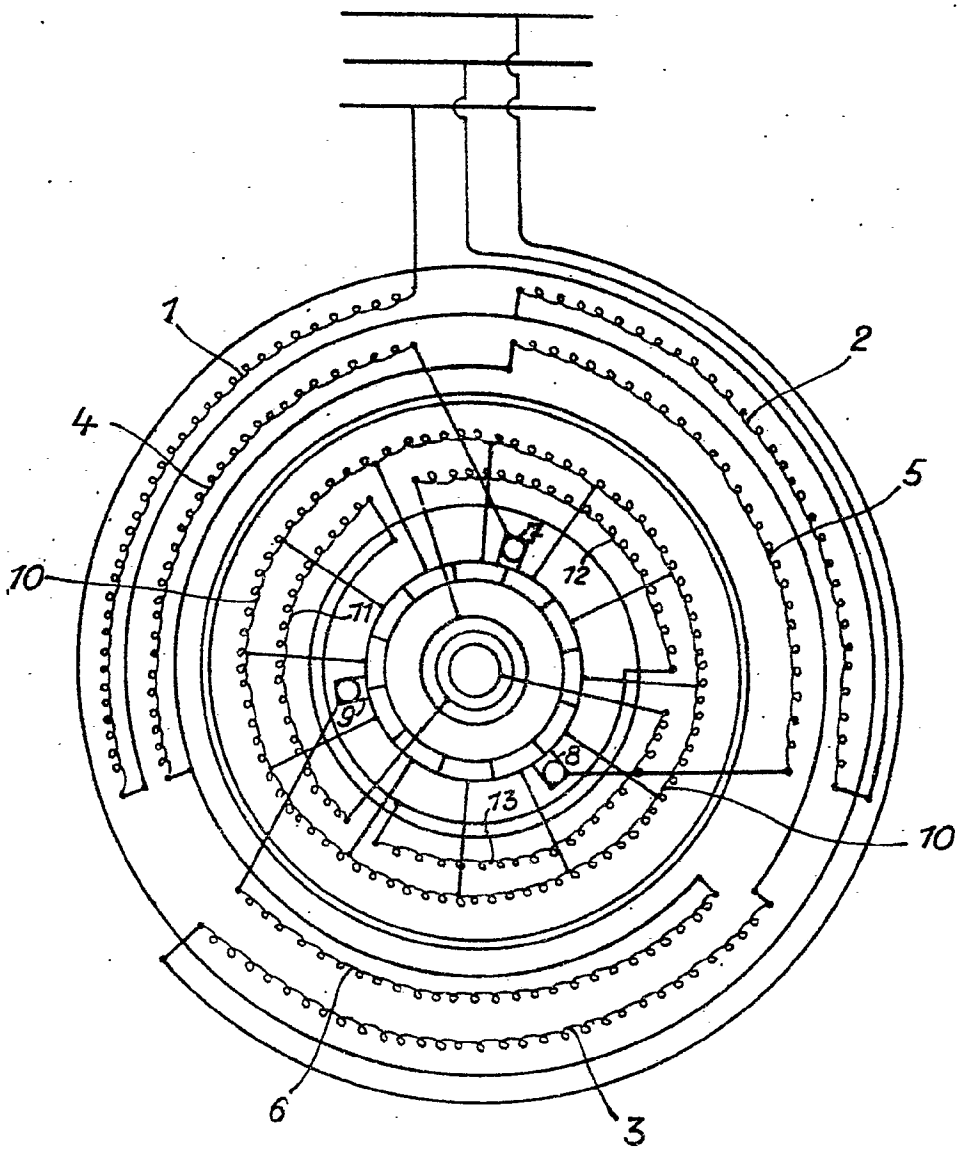
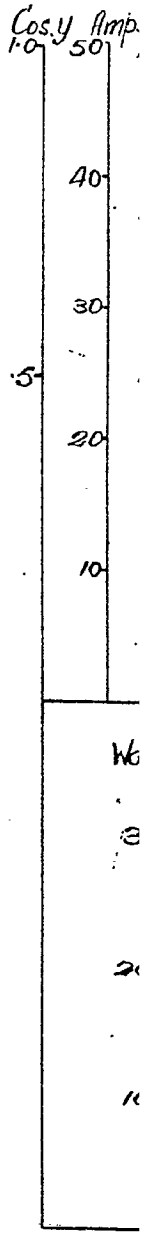


Fig. 1



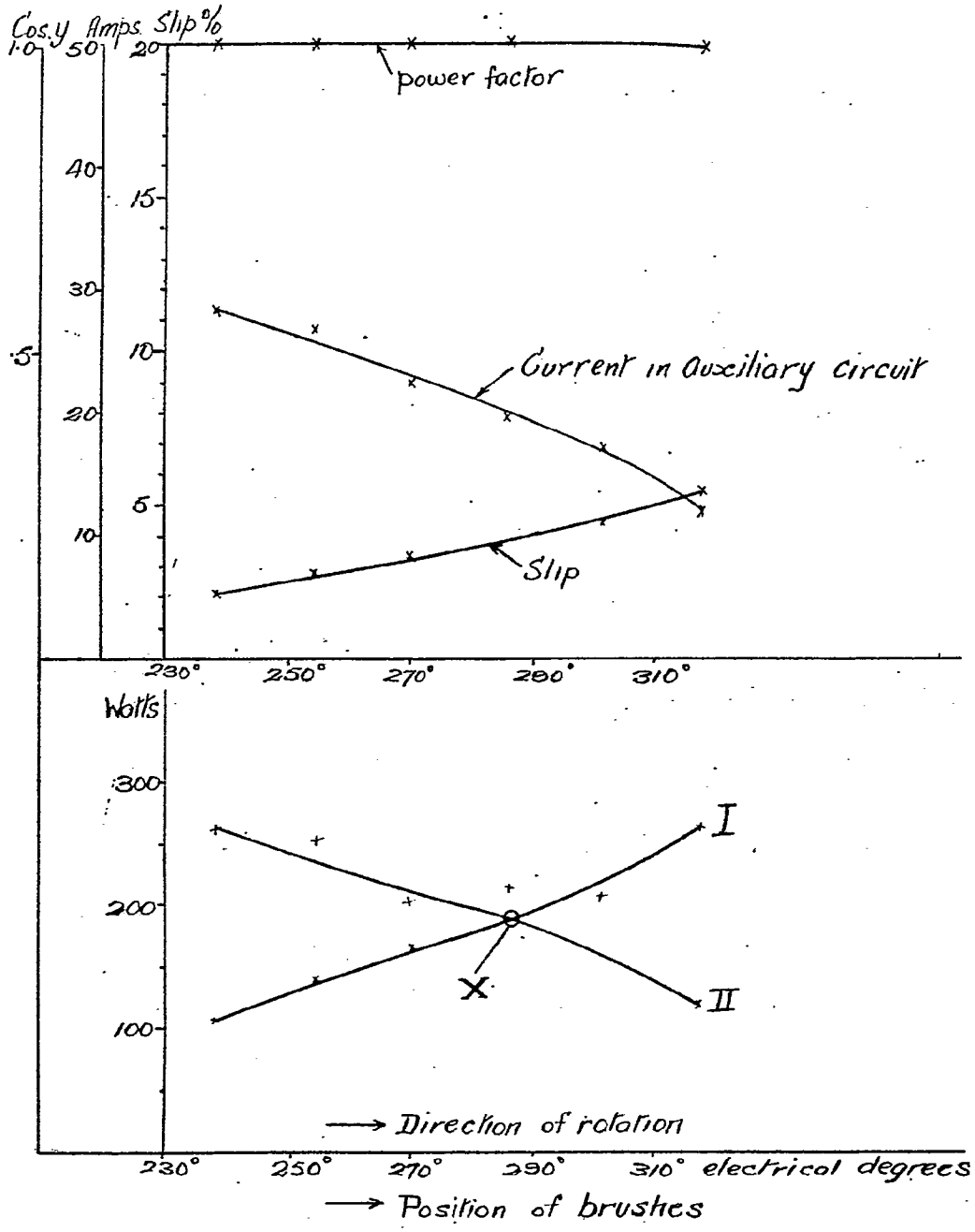


Fig. 2.

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SHEET 1

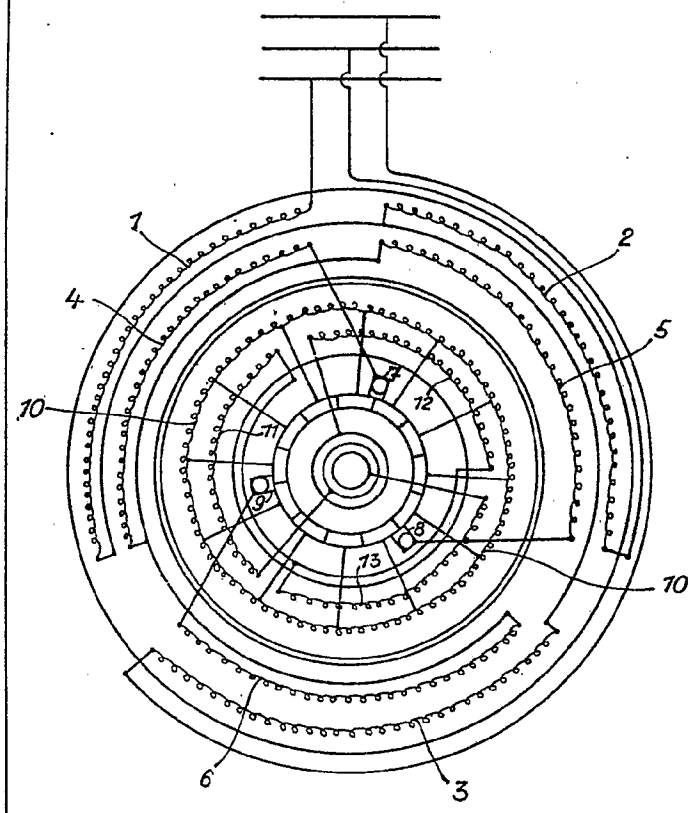

Fig. 1

SHEET 2

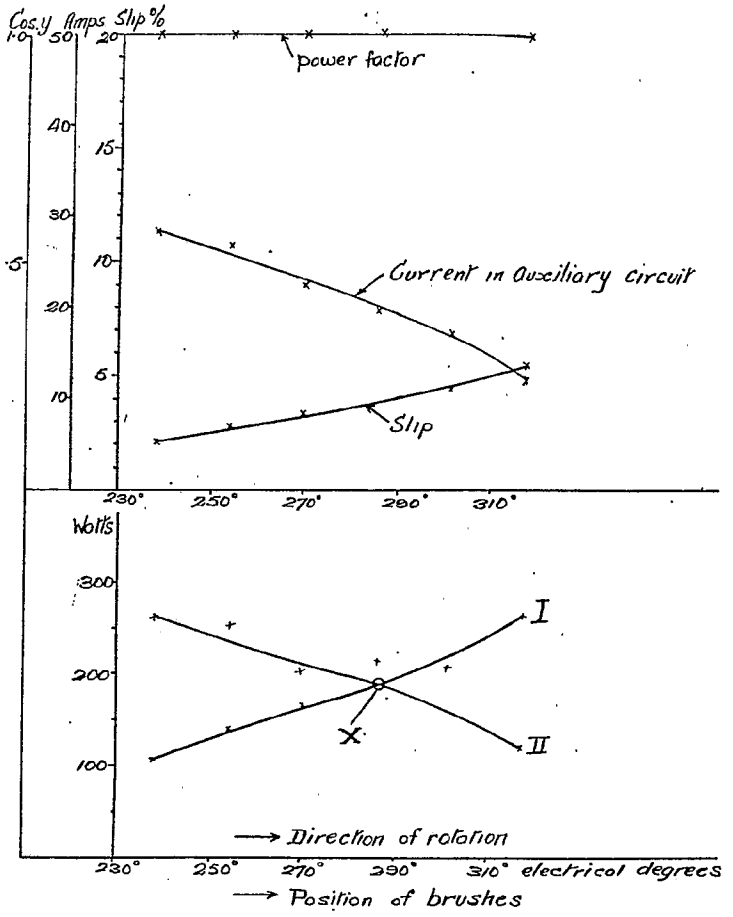

Fig. 2.

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